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# Stochastic climate dynamics: Stochastic parametrizations and their global effects

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A well-known difficulty in modeling the atmosphere and oceans' general circulation is the limited, albeit increasing resolution possible in the numerical solution of the governing partial differential equations. While the mass, energy and momentum of an individual cloud, in the atmosphere, or convection chimney, in the oceans, is negligible, their combined effects over long times are not.

Until recently, small, subgrid-scale processes were represented in general circulation models (GCMs) by deterministic "parametrizations." While A. Arakawa and associates had realized over three decades ago the conceptual need for ensembles of clouds in such parametrizations, it is only very recently that truly stochastic parametrizations have been introduced into GCMs and weather prediction models. These parametrizations essentially transform a deterministic autonomous system into a non-autonomous one, subject to random forcing.

To study systematically the long-term effects of such a forcing has to rely on theory of random dynamical systems (RDS). This theory allows one to consider the detailed geometric structure of the random attractors associated with nonlinear, stochastically perturbed systems. These attractors extend the concept of strange attractors from autonomous dynamical systems to non-autonomous systems with random forcing.

To illustrate the essence of the theory, its concepts and methods, we carry out a high-resolution numerical study of two "toy" models in their respective phase spaces. This study allows one to obtain a good approximation of their global random attractors, as well as of the time-dependent invariant measures supported by these attractors.

The first of the two models studied herein is the Arnol'd family of circle maps in the presence of noise. The maps' fine-grained, resonant landscape — associated with Arnol'd tongues — is smoothed by the noise, thus permitting a comparison with the observable aspects of the "Devil's staircase" that arises in modeling the El Nino-Southern Oscillation (ENSO). These results are confirmed by studying a "French garden" that is obtained by smoothing a "Devil's quarry." Such a quarry results from coupling two circle maps, and random forcing leads to a smoothed version thereof. We thus suspect that stochastic parametrizations will stabilize the sensitive dependence on parameters that has been noticed in the development of GCMs.

This talk represents joint work with Mickael D. Chekroun, D. Kondrashov, Eric Simonnet and I. Zaliapin. Several other talks and posters complement the results presented here and provide further insights into RDS theory and its application to the geosciences.